

Self-organization leads to supraoptimal performance in public transportation systems

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<http://turing.iimas.unam.mx/~cgg/teach/Pamplona>



<http://dx.plos.org/10.1371/journal.pone.0021469>



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Prediction vs. Adaptation

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- Prediction useful for “*stationary*” problem spaces.
- Adaptation useful for “*non-stationary*” problem spaces.



- Of which type are urban problem spaces???



Self-organization as a Method to Build Adaptive Systems

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When building a self-organizing system, elements are designed to *dynamically* and *autonomously* solve a problem or perform a function at the system level.

- Useful when solution is not reducible (complex interactions), not known beforehand, or changes constantly.
 - Non-stationary problem domains.
- As problem changes, elements adjust their behavior, adapting to the new situation and finding new solutions.





A Methodology (Gershenson, 2007)

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- An *agent* is a description of an entity that *acts* on its environment
- An observer can describe the *goals* of an agent
- The “fulfillment” of goals can be measured with a variable $\sigma \in [0, 1]$, representing *satisfaction*
- Agents *interact*, affecting each other (and their goals and satisfactions) positively, negatively, or neutrally
- *If we minimize “friction” (negative interactions) and maximize “synergy” (positive interactions), global “satisfaction” σ_{sys} will increase*
- Use *mediators* to promote and constrain behaviors that reduce friction and maximize synergy.
- Focus on interactions, not only on elements.



Public Transportation Systems

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- Urban mobility has a high impact on society.
- More than half of people living in cities, 2/3 by 2050.
- 100 million daily passengers in 100 busiest metro systems.
- Do we know how to regulate public transportation systems?
- NO!





Headways: the theory

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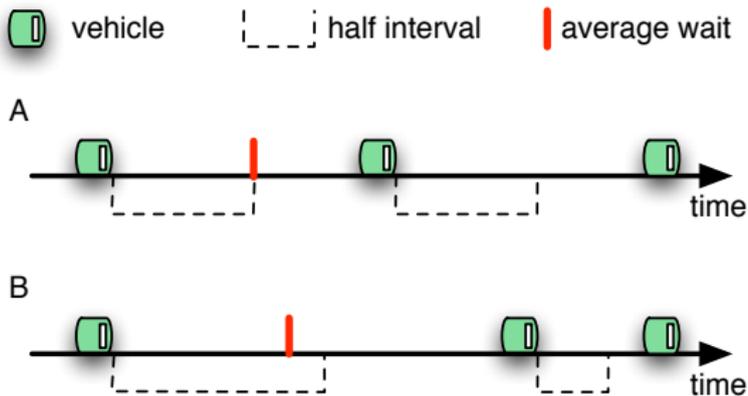
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Passenger waiting times at stations are minimized with equal headways.





Equal Headway Instability

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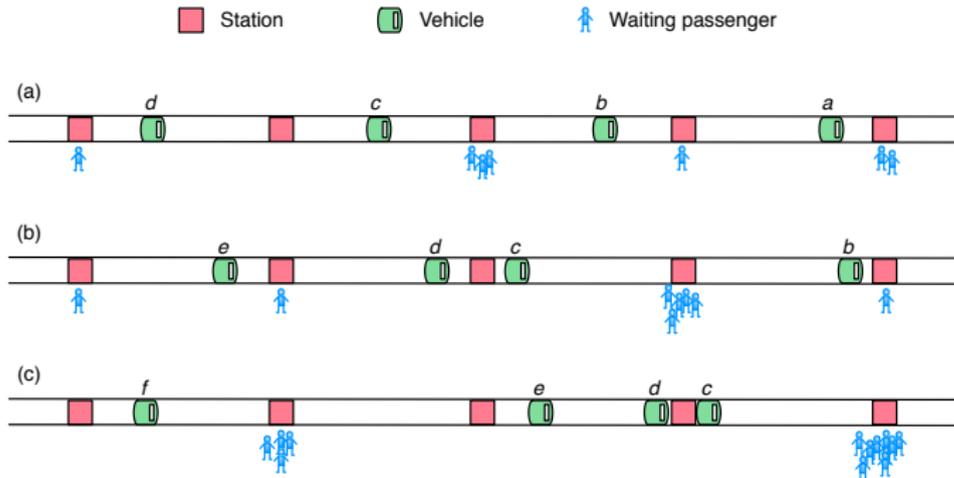
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- Gershenson, C. & Pineda, L. A. (2009). Why does public transport not arrive on time? The pervasiveness of equal headway instability. *PLoS ONE* (10): e7292. doi:10.1371/journal.pone.0007292.



Simulation

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<http://tinyurl.com/antipheromones>

- *DF*, default method: no restrictions. Equal headways always unstable.
- *MX*, adaptive maximum method: t_{min} and t_{max} , latter one adapted depending on global passenger demand. Equal headways maintained.
- *SO*, self-organizing method: antipheromones to regulate headways locally. Adaptive headways.



SO algorithm

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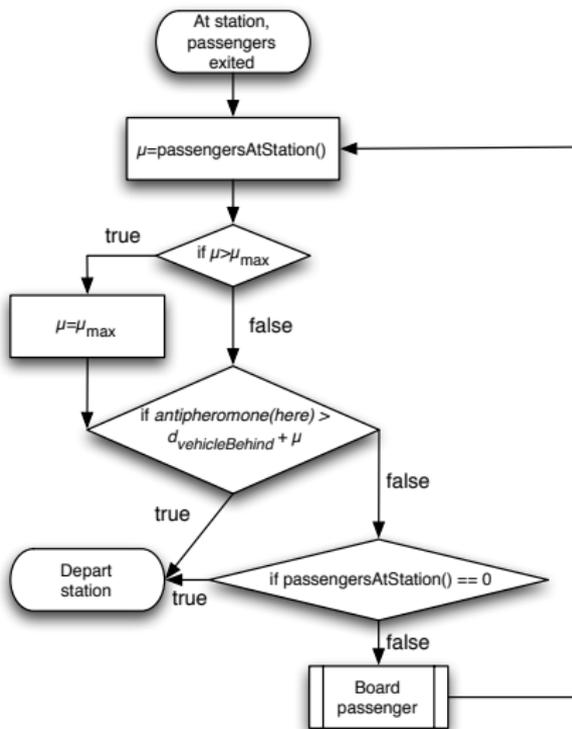
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Results: homogeneous scenario

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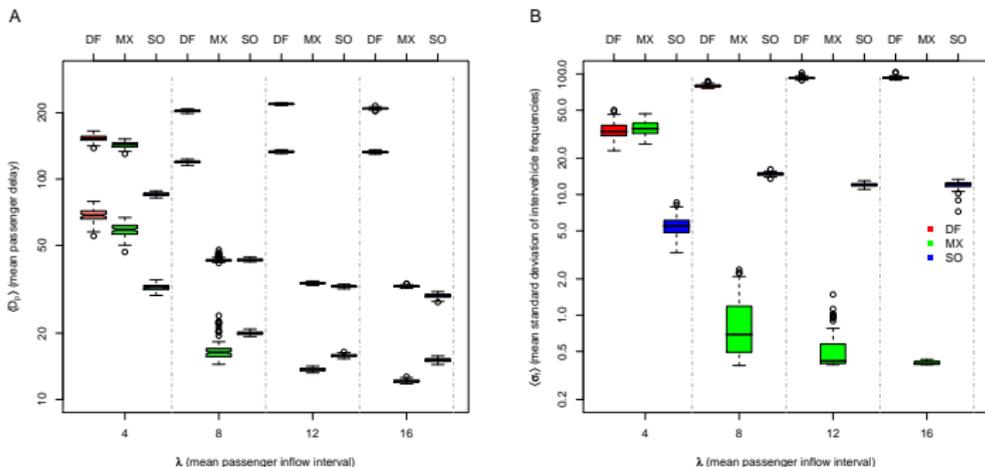


Figure: Results for homogeneous scenario. A. Passenger delays for methods: “default” (*DF*), “max” (*MX*), and “self-organizing” (*SO*), for different passenger demands (lower λ means higher demand). Lower boxes at each column show waiting times at stations. Higher boxes show total waiting times. B. Headway standard deviations. Lower σ_f implies more regular headways.



Results: heterogeneous scenario

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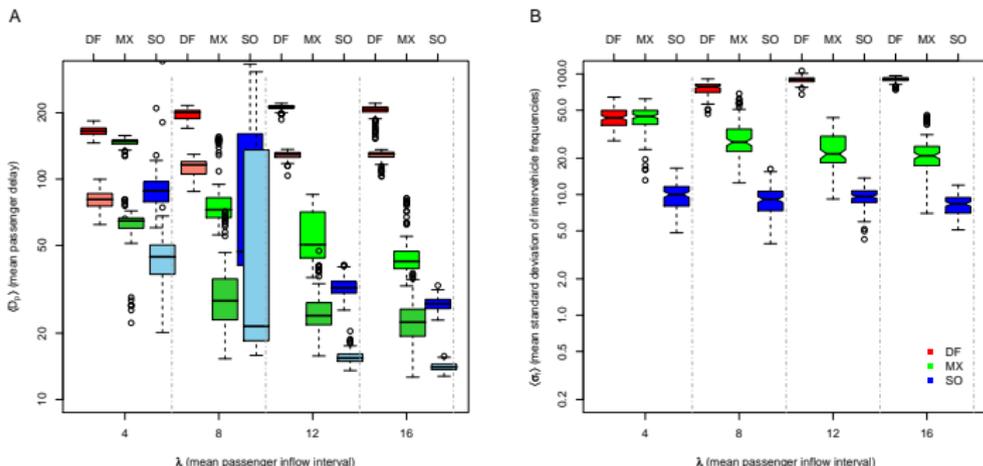


Figure: Results for heterogeneous scenario. A. Passenger delays for methods: “default” (DF), “max” (MX), and “self-organizing” (SO), for different passenger inflow intervals λ . Lower boxes, slightly shifted to the right, at each column show waiting times at stations. Higher boxes show total waiting times. B. Headway standard deviations. Lower σ_f implies more regular headways.



Discussion

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- Current theory focuses on waiting times at stations.
- 'Slower-is-faster' effect leads to supraoptimal performance.
- Solution is not predefined, adapts locally to the current situation.
- Adaptation matches timescale of system change.





Social factor...

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- Equal headway instability not only a technical, but also social problem.
- In many systems, the single source of delays which lead to instability depends on passenger behavior.
- Promote behaviors that reduce delays and thus instability.
- Provide timely information to passengers.



Future Work

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- Metro
- Metrobus
- Pumabus
- More realistic simulations
- Crowd dynamics





Conclusions

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- Equal headway instability is a general phenomenon.
- Self-organization can lead to supraoptimal performance.
 - 'slower-is-faster' effect.
 - antiphormones provide local information.
 - adaptation at appropriate timescale.
- There is a great potential impact in daily life.

